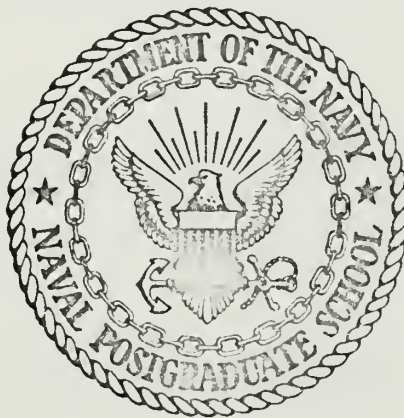ADVANCED DESIGN, ALIGNMENT AND CALI-
BRATION OF AN APPARATUS TO MEASURE
THE EFFECTIVE CROSS-SECTION OF
MOLECULAR NITROGEN WHEN BOMBARDED
BY LOW ENERGY ELECTRONS

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THESIS

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APPARATUS TO MEASURE THE EFFECTIVE CROSS-SECTION OF
MOLECULAR NITROGEN WHEN BOMBARDED BY
LOW ENERGY ELECTRONS

by

James David Fontana

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December 1971

Advanced Design, Alignment and Calibration of an
Apparatus to Measure the Effective Cross-Section of
Molecular Nitrogen When Bombarded by Low Energy Electrons

by

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Lieutenant Commander, United States Navy
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MASTER OF SCIENCE IN PHYSICS

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ABSTRACT

The design and construction of a previously incomplete apparatus was advanced in preparation for measuring the effective cross-sections for forming the $B^2\Sigma_u^+$ state of N_2^+ and the $C^3\Pi_u$ state of N_2 in the lowest vibrational level when excited by low energy electrons in the 50 to 2,000 ev range.

The equipment's electron beam and optical system were aligned and its combined optical, detection and counting system was calibrated to obtain its efficiency in counting photons emitted from the $C^3\Pi_u$ state decay. This efficiency was found to be 0.01006 ±0.00005%. The efficiency of the combined detection and counting system alone was found to be 0.617 ±0.031%.

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I. INTRODUCTION

The measurement of the effective cross-sections of Molecular Nitrogen was undertaken in support of upper atmosphere research funded by the Naval Ordnance Laboratory. The objective of this work was to provide information which would lead to the understanding of phenomena such as airglow and aurora, and to provide data to test semi-classical theories on other basic phenomena where quantum mechanical predictions are not available. The cross-sections of particular interest were those for forming the $B^2\Sigma_u^+$ state of N_2^+ and the $C^3\pi_u$ state of N_2 in the lowest vibrational level when bombarded by electrons in the 50-200 ev energy range.

The experimental apparatus was designed to excite a volume of Molecular Nitrogen with low energy electrons and to count the optical photons as the molecules return to their ground state. The work covered by this paper involved the advanced design of a previously incomplete experimental apparatus,[Ref. 1], and the alignment and calibration of this equipment so that the necessary parameters could be accurately measured and the effective cross-sections thus established.

II. DEVELOPMENT OF THE CROSS-SECTION EQUATION

The lowest vibrational level of the $B^2\Sigma_u^+$ states of N_2^+ decays by electromagnetic means to $X^2\Sigma_g^+$ state of N_2^+ in the v'' progression (0,0), (0,1), (0,2) and (0,3). The lowest vibrational level of the $C^3\Pi_u$ states of N_2 decays by electromagnetic means to the $B^3\Pi_g$ state of N_2 in the v'' progression of (0,0), (0,1), (0,2), (0,3) and (0,4). The wavelengths for the highest decay probabilities, in both cases the (0,0) transition are 3914.4 and 3371.3 Angstroms respectively.

To obtain the effective cross-sections for these (0,0) transistions, consider a small volume of nitrogen bombarded by a beam of electrons. If the duration of bombardment is greater than the mean life time of the excited state, then the excitation rate and de-excitation rates are equal and a steady state condition exists with the reaction governed by

$$(1) \qquad \frac{dN_k^*}{dt} = R_k - \sum_{f=0}^{m} \lambda_{of} N_k^* - Q = 0$$

where N_k^* is the total population of the excited state k, R_k is the rate of formation of the excited state, λ_{of} is the probability/sec of decay to the final state f, and Q is the collisional de-excitation rate.

Equation (1) can be simplified by assuming the collisional de-excitation rate Q to be negligable. If it can be shown that the mean time between collisions t_c is significantly greater than the mean life time t of the excited states, then this is a valid assumption. Thus, given that

$$(2) \qquad t_c = \frac{\bar{\ell}}{v}$$

where $\bar{\ell}$ is the mean free molecular path, and v the thermal velocity of the colliding particles, and, assuming an ideal gas where

(3) $$\bar{\ell} = \frac{1}{\sqrt{2}\,\pi d^2 n}$$ and

(4) $$v = \sqrt{\frac{3kT}{m}}$$

then

(5) $$t_c = \frac{\dfrac{1}{\sqrt{2}\,\pi d^2 n}}{\sqrt{\dfrac{3kT}{m}}}$$

where n is the number of molecules per unit volume, d is the molecular diameter, k is Boltzmann's constant, T absolute temperature and m the mass of the molecules. Thus, rearranging and substituting P for nkT, the ideal gas law

(6) $$t_c = \frac{\sqrt{mkT}}{\sqrt{6}\,\pi d^2 P}$$

Here it can be seen that if the pressure term is made low enough, the time between collisions can be made as large as necessary to have $t_c \gg t$. It can be shown, that with $t = 10^{-8}$ seconds [Ref. 2], that t_c can be $10^3 t$ by operating at pressures as high as 10^{-4} Torr. Thus the initial assumption can be made valid and

(7) $$R_k - \sum_{f=0}^{n} \lambda_{of} N_k^* = 0$$

Now, the cross-section for forming the excited state k is given by

(8) $$\sigma = \frac{eR_k}{n_G J \Delta V}$$

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where n_G is the number of molecules per unit volume in the ground state in ΔV, the interaction volume, J is the current density of the electron beam, and e is the electronic charge. In as much as $\Delta V = AL$, where A is the right circular cross-sectional area of the incoming electron beam and L is the interaction volume's length and J is defined by I/A then

$$(9) \qquad\qquad \sigma = \frac{eR_k}{n_G \, IL}$$

Let n_k^* be the number of molecules in the excited state k, then $n^* = \sum_k n_k^*$ is the total number not in the ground state. Therefore

$$(10) \qquad\qquad n = n^* + n_G$$

and substituting (7) into (9)

$$(11) \circ \qquad\qquad \frac{\sigma n_G IL}{e} = \lambda \, n^* \Delta V$$

and rearranging

$$\frac{n^*}{n_G} = \frac{\sigma IL}{e\lambda \Delta V}$$

$$\text{or} \qquad\qquad \frac{n - n_G}{n_G} = \frac{n}{n_G} - 1 = \frac{\sigma IL}{e\lambda \Delta V}$$

therefore

$$(12) \qquad\qquad \frac{n_G}{n} = \frac{e\lambda \Delta V}{e\lambda \Delta V + \sigma IL}$$

Now, if typical values from Ref. 3 are substituted into equation (12) for example

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$$\lambda = 10^8 \ \text{sec}^{-1}$$

$$\sigma \simeq 10^{-16} \ \text{cm}^2$$

$$\Delta V = 0.2 \ \text{cm}^3$$

$$I = 10^{-6} \ \text{amperes}$$

$$\text{and} \quad L = 2.22 \ \text{cm}$$

then $\dfrac{n_G}{n} = 0.99999\ldots\ldots$, and thus a very close approximation can be made that $n_G = n$. Therefore,

(13)
$$\sigma = \frac{e \, R_K}{n \, I \, L}$$

Next, equating (7) and (13)

$$R_k = \frac{\sigma n I L}{e} = \sum_{f=0}^{n} \lambda_{of} \, N_K^* = \lambda_{oo} N_K^* \sum \frac{\lambda_{of}}{\lambda_{oo}}$$

then

(14)
$$\sigma = \frac{e}{n I L} \lambda_{oo} N_K^* \sum_{f=0}^{n} \frac{\lambda_{of}}{\lambda_{oo}}$$

where $\lambda_{oo} N_k^*$ is the rate of the $(0,0)$ transition, or, the rate $(0,0)$ photons are emitted.

The count rate C observed by the detector is given by

(15)
$$C = \frac{d\Omega}{4\pi} \epsilon \lambda_{oo} N_k^*$$

where $d\Omega$ is the solid angle formed by the detector assembly and ϵ the efficiency of the total collection and counting system. Rearranging equation (15) leads to $\lambda_{oo} N_k^* = \dfrac{4\pi C}{\epsilon \, d\Omega}$ and substituting back into equation (14) gives

(16)
$$\sigma = \frac{e}{nIL} \frac{4\pi C}{\epsilon d\Omega} \sum_{f=0}^{n} \frac{\lambda_{of}}{\lambda_{oo}}$$

Again envoking the ideal gas law $n = \frac{P}{kT}$ and substituting

(17)
$$\sigma = \left[\frac{4\pi K}{d\Omega \epsilon L}\right]\left[\frac{TC}{IP}\right]\left[\sum_{f=0}^{n} \frac{\lambda_{of}}{\lambda_{oo}}\right]$$

This is the excitation cross-section equation. The first bracket is a function of equipment design, with the $1/\epsilon$ term the subject of the system's calibration. The second contains the equation variables, temperature, pressure, current and count rate and the third bracket contains the transition probabilities which may be obtained from Ref. 2.

III. EXPERIMENTAL APPARATUS

The experimental apparatus consists of six major components:
a) the outer chamber, b) the interaction chamber (IAC), c) the vacuum
pumping system, d) the electron gun, e) the optical system, and f) the
detection and counting equipment. A schematic of the total assembly
can be seen in figure (1) and the major components are described below.

A. THE OUTER CHAMBER

The outer chamber consists of a large right circular cylinder, with
an eighteen inch diameter, housing the interaction chamber, and a smaller
right circular cylinder tipped on its side containing the electron gun.
The electrical connections for the interaction chamber and the electron
gun pass through glass feed throughs and coaxial connectors in the chamber
walls. Inlets are also provided for pressure measurements, the N_2 gas
line, and the optical tube from the IAC to the detector. Pressure in the
chamber is measured with an ion gauge and the vacuum maintained by two
pumping systems located at each end of the chamber.

B. INTERACTION CHAMBER

The interaction chamber is that volume wherein collisions between the
electrons in the beam and the nitrogen molecules take place. The IAC,
shown in figure (2), actually consists of two concentric chambers. The
larger one is a five and five-eighths by two inch diameter cylinder with
one end tapered and the other end sealed by a flat circular faceplate.
The faceplate, which is insulated from the remainder of the chamber, has
a one-eighth inch diameter hole in the center to admit the electron beam.
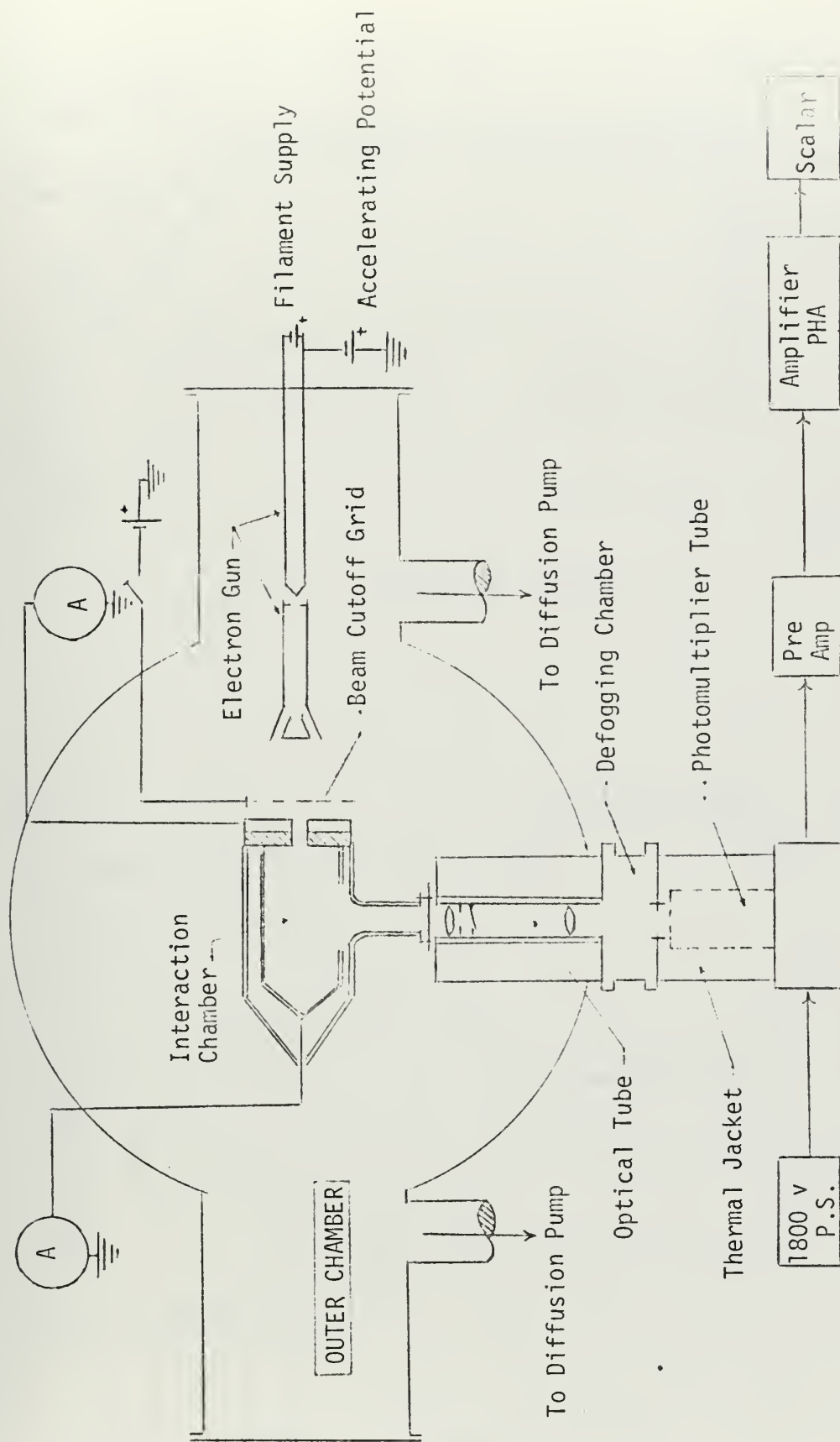The smaller container is similar in shape and is fitted inside of and

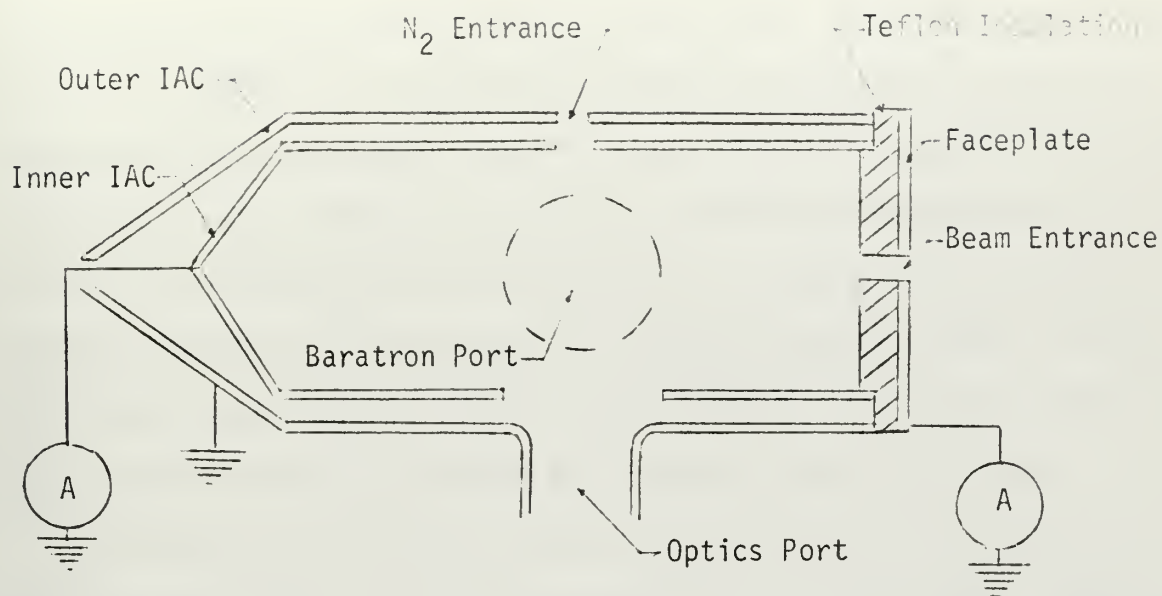FIGURE 1. EXPERIMENTAL APPARATUS

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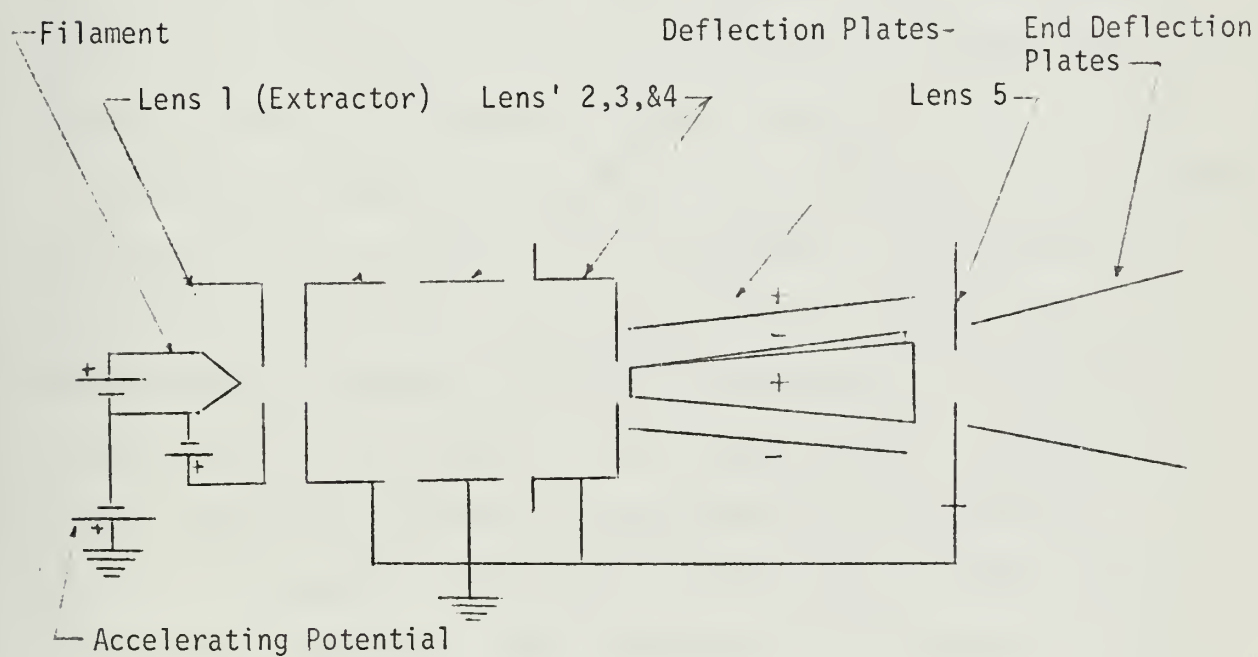FIGURE 2.   INTERACTION CHAMBER

FIGURE 3.   ELECTRON GUN SCHEMATIC

insulated from the larger one and the face plate. This design was necessary to shield the interaction volume from an excessive number of stray electrons originating from the electron gun. These electrons were erroneously being counted as part of the interacting beam without actually contributing to the interaction. As constructed, therefore, electrons which strike the outer IAC wall are passed to ground and only those which pass through the one-eighth inch hole in the face plate can enter the interaction volume and be counted as part of the beam.

In as much as the beam that leaves the electron gun diverges to a diameter greater than that of the entrance hole, a significant fraction of the beam falls on the faceplate. These electrons are collected and measured on a Keithley 410 micro-micro ammeter. This serves both as a beam alignment aid and as a useful measurement of the gun's gross output. Those electrons that are focused through the hole impact on the copper wall of the inside chamber and are also measured by a Keithley 410. Currents as high as 10^{-6} amperes have been recorded.

Various connections are fitted to the IAC to provide for the initiation of nitrogen into the chamber and the measurement of the parameters of pressure and photon count. The nitrogen flow is regulated via a Granville-Phillips Company Variable Leak Valve and can be controlled as closely as 10^{-10} cc per second. Three independent means for measuring chamber pressure are provided; a thermocouple, an ion gauge and a Baratron 170M Barometer. The first two devices were provided simply to obtain order of magnitude figures and because of their ease of operation have been extensively used when accurate measurements were not required. The Baratron, however, is a very precise measuring instrument and is capable of recording differences as small as 10^{-5} torr. This instrument

is connected with its high pressure side to the IAC and its low pressure side to a reference vacuum of 10^{-7} torr. With a pressure of 10^{-4} torr in the IAC, the Baratron essentially reads absolute pressures.

C. VACUUM PUMPING SYSTEM

The vacuum pumping system for the reaction chambers consists of a modified CHA IND Model S-600 series high vacuum system. The system has two six inch oil diffusion pumps rated at 1800 liters per second each, which discharge to a single 15 cfm mechanical pump. While both diffusion pumps are required when nitrogen is injected into the vacuum chambers, only one is necessary when other system's tests are being run as it is capable of maintaining pressures as low as 10^{-6} torr as long as nitrogen is not introduced.

A second vacuum system, also a CHA IND Model, is used to sustain a reference vacuum for the Baratron. It has maintained pressures as low as 10^{-8} torr.

All three diffusion pumps require the use of refrigerated baffles to prevent oil from entering the vacuum chambers. The CHA holding pump is cooled automatically by a freon system, while the other two use liquid nitrogen and require careful monitoring.

D. ELECTRON GUN

The electron beam is generated by an RCA 7JP-4 TV Tube electron gun, shown in figure (3), with a directly heated V shaped cathode made of 0.010 inch diameter tungsten wire. The focusing and deflection systems are left intact, however, lens' 2, 3, 4 and 5 and the end deflection plates are maintained at ground potential. The accelerator voltage is

connected between the cathode and ground with the cathode negative. The
IAC is also grounded and electrons leaving the cathode are accelerated
toward the grounded chamber. As previously mentioned, the beam enters
the chamber through a hole in the face plate. In as much as the IAC is
field free, the electrons experience an energy equal to the accelerating
potential in electron-volts.

E. OPTICAL SYSTEM

The optical system was designed to collect photons emitted from the
IAC at right angles from the beam and transmit them to the detection and
counting apparatus. The system consists of two positive lenses, an
interchangeable narrow band filter, an aperture stop and a field stop,
all fitted in a brass tube.

The first lens is mounted with its focal point set at the center of
the electron beam, thus passing parallel light through the brass tube to
the second lens. Immediately following the first lens is a 7/8 inch
aperture stop. This has the dual function of ensuring uniform brightness
of the object beam, and of establishing limits on the solid angle viewed
by the optical system.

The narrow band filters were chosen so that the appropriate transition
wave lengths could be selected from the spread of all possible transitions.
Filters with peak wavelengths of 3950 and 3400 Angstroms were selected to
be used for the 3914 and 3371 Angstrom lines respectively. The peak wave-
length passed by each filter was altered to bring it closer to the
transition line of interest by changing the angle of incidence of the
incoming light. As the angle is increased, the peak wavelength transmitted
is shortened. The appropriate angles were estimated mathematically and

adjusted using a Bausch and Lomb Photospectrometer. The angles selected were 10° and 20° respectively. Both filters have a 60 Angstrom bandwidth.

From the narrow band filter, the parallel light rays continue on to the second positive lens where they are focused on a 0.125 by 0.708 inch rectangular field stop at the mouth of the detector. This large rectangular "slit" is positioned to limit the field of view seen by the optical system and more specifically to define the interaction volume.

A quartz window seals the optical tube from the evacuated chambers. Thus, the entire optical system can be removed from the experimental apparatus without destroying the chamber's vacuum. This allows the experimentor the option of calibrating the optical, detection and counting systems without interrupting the continued design and testing of the bulk of the experimental apparatus. Indeed he is able to calibrate on a daily basis should he choose, with minimum disruption.

F. DETECTION AND COUNTING EQUIPMENT

The photons collected by the optics are detected by an RCA 6810A photomultiplier tube. In order to maintain the photomultiplier's dark current at its lowest possible level, the tube is cooled to a $-72°C \pm 1°$ by passing liquid nitrogen boil off through a copper jacket surrounding the tube. The boil off is generated by electrically heating a 110Ω carbon resistor submersed in a large dewar of liquid nitrogen. The pressure from the boil off in the dwar forces the exit of liquid nitrogen where it is channeled through an Union Carbide TC-1 Liquid Nitrogen Controller. This controller has the two fold purpose of ensuring that only gaseous nitrogen passes to the tube's insulating jacket so that its linearity and stability are not destroyed by the extreme cold, and of regulating the temperature of the gas in the jacket to maintain consistency

and eliminate any temperature gradient across the tube. The latter can
be accomplished to within $\pm 1°C$ by a feed back temperature sensing device
at the insulating jacket's exhaust post. A thermistor is placed between
the jacket and the tube walls and measured by a multimeter so that the
temperature can be monitored.

To prevent the photomultiplier face from frosting over due to the
extreme cold, a defogging chamber was added between the photomultiplier
and the optics tube. Initially cold dry nitrogen gas was passed through
the chamber, and though this prevented the tube from fogging, it had the
added effect of increasing the photon count. The chamber was finally
placed under a vacuum using a portable mechanical pump. This works
extremely well as it has the added benefit of reducing the dark current
by 80%.

The signal from the detector is then passed through a Hewlett Packard
10615A preamplifier, a Hammner DDL amplifier, and a Hamner NC-14 Pulse
Height Analyzer to a Hewlett Packard 5202L Scalar-timer. This equipment
is adjusted to provide maximum signal to noise ratio.

IV. ALIGNMENT AND CALIBRATION

The systems alignment involves those procedures that are necessary to achieve an observable interaction between the nitrogen and the electron beam. Specifically, it comprises the guiding of the electron beam into the interaction chamber and the precise placement of the optics so that the resulting emissions will be seen by the detector. Calibration, on the other hand, involves the obtaining of a value for the efficiency of the optical, detection and countings systems so that an effective excitation cross section can be calculated. Both procedures are examined below.

A. ALIGNMENT

1. Electron Beam

The alignment of the electron beam was accomplished to ensure that the electron beam did in fact enter the interaction chamber. The rough alignment was accomplished with the aid of a small laboratory He-Ne Lasar. This instrument, which was chosen for its finely defined light beam, was positioned so as to shine along the longitudinal axis of the gun, through the small hole in the gun's extractor lens and into the hole in the IAC's faceplate. A shielded cable, running from the center of the chamber's tapered back end to the ammeter, was removed leaving a small hole with which to complete the collimation. See figure 4. Thus, by adjusting the IAC's mounting brackets until the Lasar light could be observed illuminating a screen positioned behind the chamber, the rough alignment was achieved.

The fine adjustments were made by applying the appropriate voltages across the gun's deflection plates. In as much as difficulty
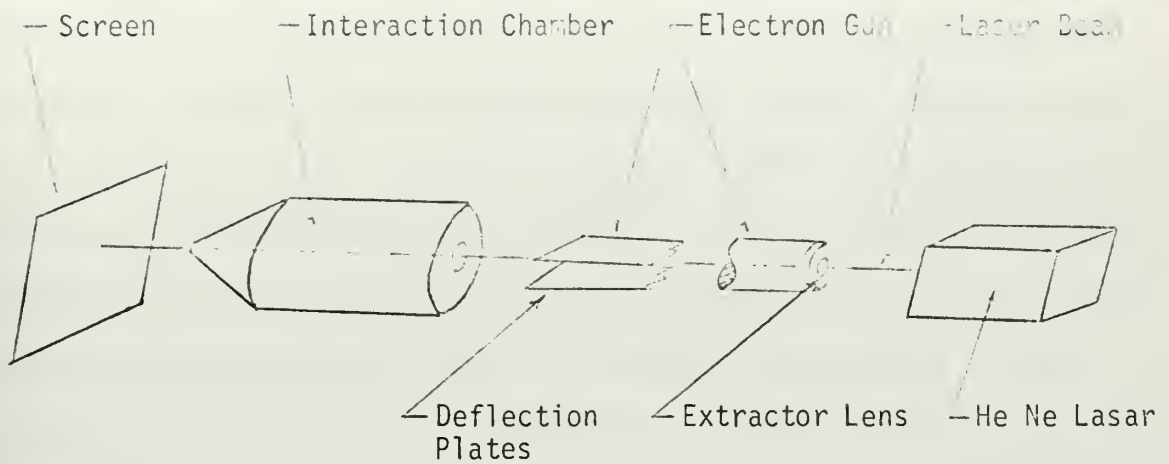
Screen —Interaction Chamber —Electron Gun —Laser Beam

—Deflection Plates —Extractor Lens —He Ne Lasar

FIGURE 4. ROUGH ELECTRON BEAM ALIGNMENT

Standard Source — —Calibration Extension —Optical Tube

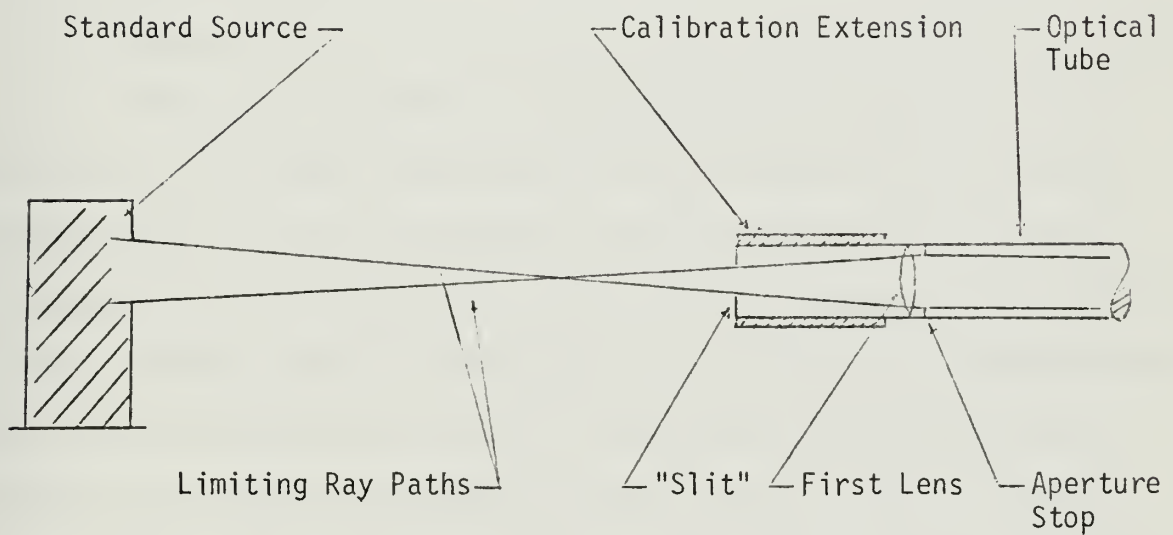Limiting Ray Paths— —"Slit" —First Lens —Aperture Stop

FIGURE 5. CALIBRATION RAY PATH DIAGRAM

was anticipated, provisions were made to read the current being collected by the chamber's face plate as well. This proved to be an excellent diagnostic tool for initial readings indicated the face plate current to be several times lower than the IAC current. Unlikely, in light of the fact that no interaction with nitrogen had been observed. At this point a negatively biased screen was mounted in front of the face plate. When the IAC current could not be cut off with the screen biased to the accelerating potential it was apparent that the IAC reading was not a result of a perfectly aligned beam. This led to the construction of the inner-outer interaction chamber, mentioned earlier, to shield the inter-action volume from stray electrons. Alignment then proceeded smoothly with deflection potentials of only a few volts required to bring the beam into sharp focus. An IAC current of the order of 10^{-6} amperes has been achieved to date.

2. Optical

The optical alignment involved nothing more than placing the first lens at its focal length away from the center of the IAC and the second lens at its focal length away from the field stop at the end of the optical tube. To insure that lens one was in fact correctly positioned a small diameter brass rod, roughened at its mid-point was threaded through the front and back holes of the IAC so that the rough section could be brought into focus by adjusting the position of the lens. The focal length of lens two was measured on an optical bench by focusing parallel light through the lens onto a ground glass screen. It was then fitted into the optical tube so that it would be this·distance away from the field stop.

B. CALIBRATION

The combined optical, detection and counting system was calibrated in order to determine a value for the system's overall Efficiency,ϵ, in detecting photons resulting from the (0,0) transition of the Second Positive Band System of N_2. Simply stated, the efficiency is the ratio of the number of counts recorded on the scalar to the number of photons entering the optical tube. The procedure was one of illuminating the system with a source of known intensity, calculating the amount of energy, in photons, entering the optics and then comparing this with the count recorded on the scalar.

The equipment arrangement for the calibration was designed to be easily and rapidly set up when changing from a data to a calibrating run, and to insure that all of the important parameters such as distance, vacuum and temperature remain unchanged. In preparing to calibrate, the photomultiplier assembly was removed from its position on the outer chamber with its defogging and cooling systems intact. This assembly was then mounted on a vertically adjustable stand and a flange was fitted at the forward end of the defogging chamber to hold the optical tube. An extension was slid over the end of the tube with a slit, the size of the field stop capping its end. This slit was positioned at the focal point of the first lens thus functioning as the object of the lens system, replacing the would be interaction volume.

The standardized light source was an EG&G Model 590 calibrated lamp system which was designed to closely approximate a Black Body source. The lamp was standardized at a distance of 50 cm from its filament. A variable diameter iris controlled the ray path of light exiting the lamp and was adjusted to 3.3 cm in diameter to insure that all the light passing

through the leading slit entered the optical tube. See figure 5. In as
much as the lamp's intensity was sufficiently high to completely saturate
the phototube, the entrance to the optics tube was positioned at four
times the standardized distance to reduce the energy density by $1/16^{th}$
and a series of neutral density filters were placed before the slit to
further alternate the energy flux to a tolerable level.

The efficiency of the combined optical, detection and counting system
was calculated by taking the product of the transmissivity of the optic
tube's narrow band filter at 3371 angstroms by the efficiency of the
detection and counting system. That is

(18) $$\epsilon_{total} = \epsilon_f \times \epsilon_{D\&C}$$

The transmissivity or efficiency of the narrow band filter was
ascertained on the Photospectrometer which provided a plot of percent
transmission versus wavelength. See figure 6. This particular band pass
characteristic was chosen so as to maximize the (0,0) transition wave-
length for the Second Positive Band System, 3371A, and minimize all
others. The next most significant spectral line, resulting from the
(2,3) transition of the same band system, has a probability of occurence
one tenth that of the (0,0) transition. When passed through the filter,
this resulted in one count of seventy-two being attributed to this line.
This was well within experimental accuracy and was, therefore, neglected.

It was at this point that difficulty was encountered in attempting
to calibrate the equipment for the First Negative Band System. The narrow
band filter selected was to pass the most intense line of the (0,n)
progression, 3914Å. Unfortunately, with a 60 Å bandwidth, the filter also
allowed the 3884 Å line from the (1,1) transition of the same band system,
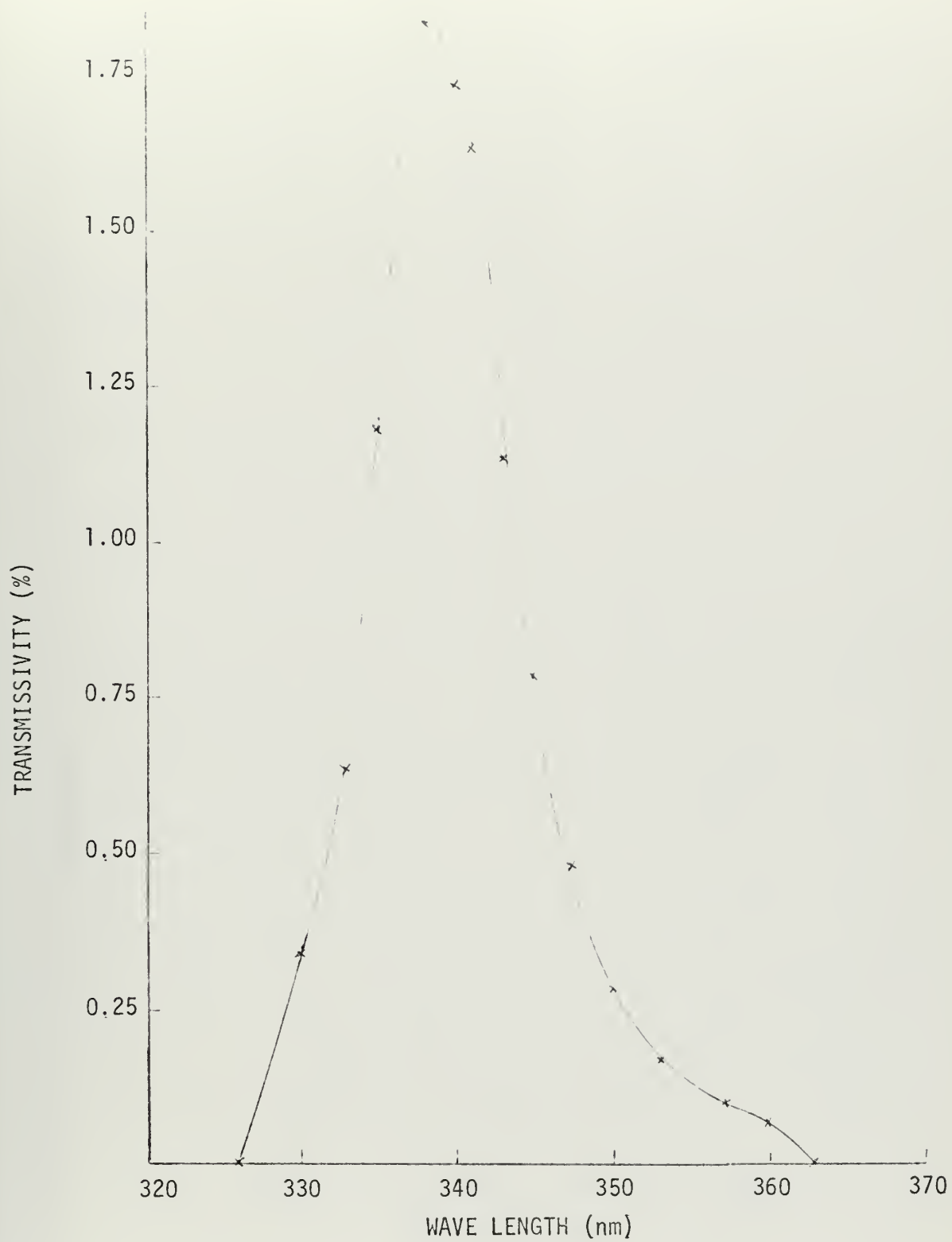
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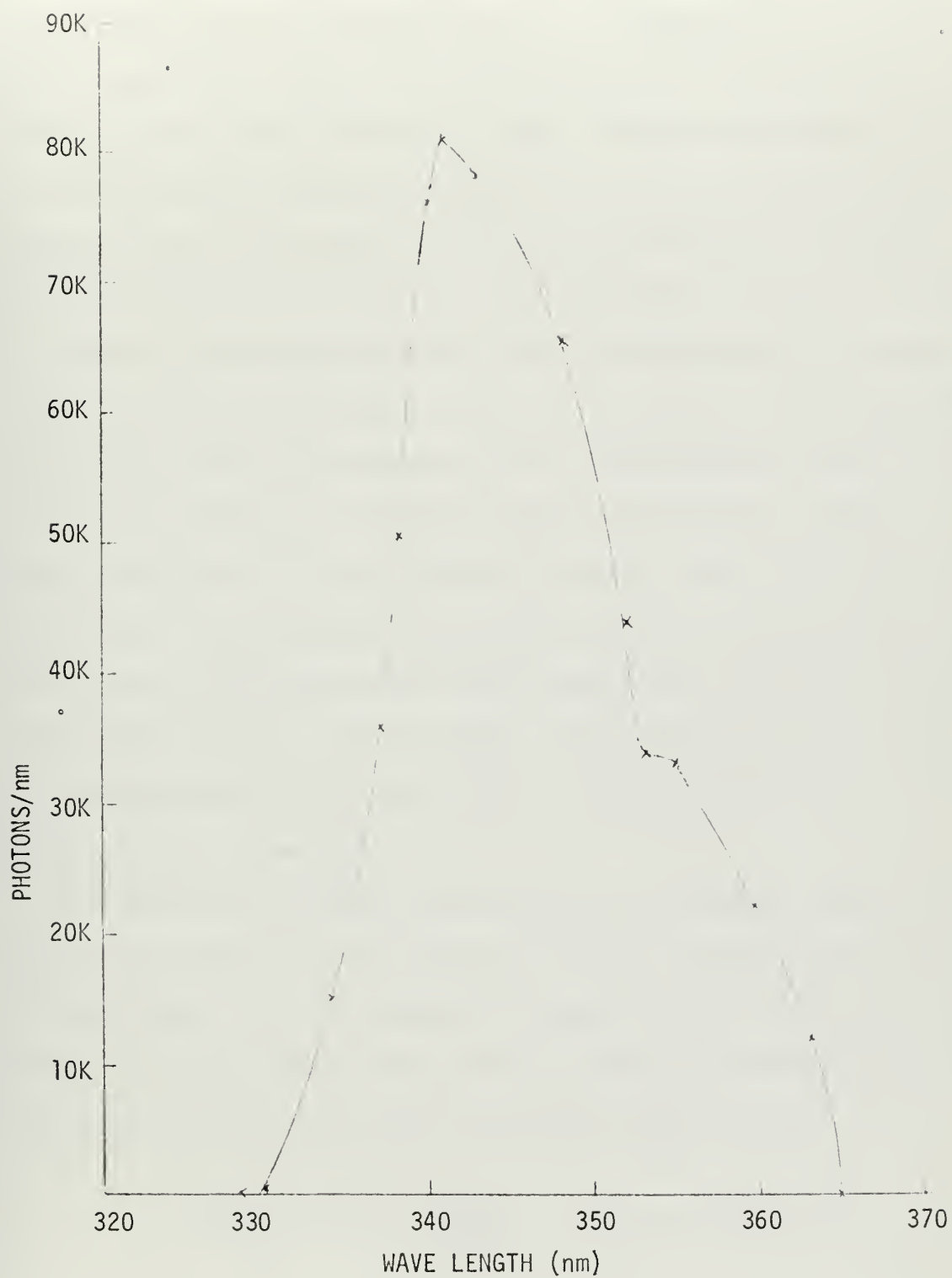FIGURE 6. 3371A NARROW BAND FILTER

FIGURE 7.   SYSTEM CALIBRATION CURVE

and more significantly, the 3894 Å line from the Second Positive Band System. Though data concerning the relative probabilities of occurence within a given band system was available [Ref.2], such data relating different band systems, particularly under conditions of different excitation energy and gas pressure was not. It was, in fact, the very goal persued in part by this paper to obtain such information. In future attempts to calibrate for the First Negative System two possible directions are suggested. The first would be to use a monochronometer in place of the optical filter, to narrow the band pass around 3914 Å to 10 Angstroms. This has the primary disadvantage of significantly reducing the intensity of the line of interest. The second suggestion would be to select a narrow band filter with the transmission peaked at one of the other lines in the band. The (0,3) transition, 5228 Å, appears to be the most favorable in that a 60 Angstrom band width filter would be free of any other significant transition. Unfortunately, the intensity of this line is one one-hundredth of that of the (0,0) wavelength and difficulty in detection may be encountered.

In calculating the overall efficiency of the combined system for the Second Positive Band the total number of photons incident on the photo-multiplier tube was first determined. Beginning with the energy density tables, in Watts/cm^2-nm, provided with the standard lamp [Ref.4], the total energy entering the optical system was computed where

$$\frac{\text{Total energy}}{\text{nm}} = \frac{\text{Energy}}{cm^2\text{-nm}} \times \text{Area of entrance slit}$$

Neutral density filters of nominal density 0.5, 1, and 2 were used to attenuate the light entering the slit. Actually, the filters were far from neutral in the range used and their characteristics were ascertained on the Photospectrometer.

Having corrected for the attenuating filter, the total energy incident
on the detector was calculated using

(19) $$E_{total}(watts) \quad = \quad \int_{\lambda_0}^{\lambda} P_\lambda V_\lambda \, d\lambda$$

where P_λ is the function representing the distance and filter attenuated
energy in Watts/nm incident on the optical tube, V_λ the transmissivity
curve of the 3371 Å narrow band filter and $d\lambda$ its wave length range in
nanometers. The $P_\lambda V_\lambda$ curve was plotted in figure 6 after having converted
the Watts to photons. The integration was actually performed graphically.
The watts to photons conversion employed the photon energy relation

(20($$E = h\nu$$

where h is Plank's constant and ν the frequency of the spectral line.
Therefore the number of photons was determined by

$$\frac{E}{h\nu} = \frac{Watts/nm}{(Joules\text{-}sec)(sec^{-1})} = \frac{Joules/sec/nm}{Joules} = Photons/sec/nm$$

The total number of photons incident on the detector, the area under the
$P_\lambda V_\lambda$ curve was 1,342,200 ±5%. The 5% tolerance was a function of the
standard lamp.

In making a calibration run a total of one hundred, ten-second, intervals
were recorded. The amplifier was set at full gain and the discriminator
set at 39 in the integral position. The recorded count rate was

$$8285 \pm 100 \text{ counts/sec}$$

Thus the resulting detection and counting equipment efficiency $\epsilon_{D\&C}$
was equal to

$$\epsilon_{D\&C} = \frac{\text{count rate}}{\text{total photon count}} = \frac{8285}{1,342,200}$$

$$= 0.00617 \pm 0.00631$$

Therefore, the total counting efficiency in recording the cross-section giving rise to the lowest vibrational level of the Second Positive Band System of N_2 is

$$(18) \quad \epsilon_{total} = \epsilon_f \times \epsilon_{D\&C} = 0.0163 \times 0.00617$$

$$= 0.001006 = 0.01006 \pm 0.00005\%$$

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13. ABSTRACT

The design and construction of a previously incomplete apparatus was advanced in preparation for measuring the effective cross-sections for forming the $B^2\Sigma_u^+$ state of N_2^+ and the $C^3\pi_u$ state of N_2 in the lowest vibrational level when excited by low energy electrons in the 50 to 2,000 ev range.

The equipment's electron beam and optical system were aligned and its combined optical, detection and counting system was calibrated to obtain its efficiency in counting photons emitted from the $C^3\pi_u$ state decay. This efficiency was found to be 0.01006 $\pm$0.005%. The efficiency of the combined detection and counting system alone was found to be 0.617 $\pm$0.031%.

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